A RAND NOTE

THE FORMATION OF PIONEER PLANT PROJECTS IN CHEMICAL PROCESSING FIRMS

S. Bodilly, R. Horvath, M. Lieber

August 1981

N-1720-DOE

Prepared For The Department of Energy

Rand
SANTA MONICA, CA. 90406

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PREFACE

In a two-year effort Rand has studied the accuracy and reliability of initial cost and performance estimates for innovative plants generated for investment decision purposes. The effort has been undertaken to understand and quantify the causes of cost growth in innovative projects similar to those DOE will be involved with.

One Rand report has focused on areas of cost and performance estimation in pioneer process plants, and used statistical analysis to determine factors of cost growth.*

The purpose of this study is to determine and detail the process, mechanisms, and information that firms use in estimating cost, performmance, and risk of innovative plants. The focus of this study is on project formation; that is, the process of bringing a technical idea through R&D to the executive decision to proceed to project definition.

This work was performed for the Office of Resource Application under contract DE-AC01-79PE70078. The data for this study were given to Rand under written nondisclosure arrangements by firms in the chemical, oil, minerals, and engineering industries. The data are presented in such a way that no company, plant, or individual can be identified.

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*See E. Merrow, K. E. Phillips, C. Myers, Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants, The Rand Corporation, R-2569-DOE, forthcoming.

SUMMARY

This Note discusses the process and techniques a sample of firms in the chemical processing industry use to ensure accurate, complete estimates and information in their project formulation for innovative process plants. Our focus is on the estimates and project proposals generated prior to project definition. The findings are based on conversations with representatives of ten chemical/petrochemical firms. All of the firms are involved with the design, construction, and operation of innovative (first-of-a-kind) process plants.

We were motivated to undertake this exploratory study by previous Rand work in related areas. In recent years many innovative capital projects have had cost overruns and poor plant performance. Results of Rand's Pioneer Plant Study (Merrow, Phillips, and Myers, forthcoming) show that information was available at the time the estimates were made which could have reduced the estimation error. In this study we looked at how firms were adapting to past estimation error and the ways they sought to improve estimation accuracy.

Through literature and field research we were able to discover the general approach that firms use to gather, refine, and disseminate information needed for investment decisions. Similarities and differences were found between the firms. First, although firms do use the same general approach, they vary because of differences in assets, managerial talent, production needs, and experiences. The most striking

similarities were trends toward (1) increased open communication among corporate functions (finance, engineering, and so on) involved in the project; (2) increased inputs and review of the information from different disciplines; and (3) increased informality to encourage information flow. Firms used several management techniques to ensure the inclusion and consideration of a broad spectrum of information. In particular, most firms required early inputs by environmental and regulatory functions, consensus and review by all involved functions, and the early formation of project teams whose members came from various corporate functions.

We found that firms, even those with large assets, did not use sophisticated, highly technical analytic methods to arrive at estimates of project cost, performance, and technical risk. Firms varied in their approaches to analysis, but all relied heavily on expert judgments to form estimates. Few performed analysis of historical data or sophisticated risk assessments because they believe that the input data are often not available and that many techniques cannot be applied under the conditions of uncertainty inherent in innovative projects. Thus, experts in the firm were relied on to use their judgment and experience to arrive at estimates. It is because of the uncertainty and inability to quantify unknowns that such heavy emphasis is placed on increased communications and informality.

This report should provide DOE and the general reader with some insight into the workings of the corporate innovation process. The following policy implications of our findings apply to the government role, especially to the Department of Energy, in encouraging innovative technologies, in estimating the cost and timing of technology commercialization, and in comparing possible alternative estimates for accuracy:

1. In comparing and assessing estimates of new technologies DOE should be aware of the variance in methods and analyses that each firm uses. Although we noted throughout our sample trends toward more accurate methods, some firms appear to be better at encouraging accurate information than others. DOE will be able to discern differences in accuracy only through careful scrutiny of the firms' estimation process. Further, higher cost estimates may actually be more accurate because they take into account many diverse factors. Lower estimates may be so because factors such as environmental concerns were overlooked.
2. Each firm has developed a unique information gathering process. Gathering all the relevant information takes time, and is not easily regulated by rigorous rules. Regulations--for example, requiring strict scheduling--may be harmful to this process.
3. We found that some firms in our sample still used poor management techniques and did little quantitative analysis. Firms may benefit by adopting the use of selective, sophisticated analytic techniques which may result in more accurate estimates.

If policies could be adopted that combined the use of quantitative analysis with the preferred informal exchange of information on all levels, then one would expect more accurate and complete estimates. Few firms in our survey have combined both these approaches.

CONTENTS

I. INTRODUCTION

MOTIVATION AND PURPOSE

To carry out its responsibilities successfully, the Department of Energy (DOE) needs accurate information about the costs and performance of new energy technology development and commercialization. The DOE is responsible for funding and controlling expenditures on research and development projects, for accurately predicting energy supply trends and commercial innovations affecting supply, and for encouraging innovation and development. To do these things the Department must be able to evaluate estimates of cost, performance, and the scheduling of innovative energy supply technologies, and to predict how a firm will react to changes in its environment, including changes in its subsidy packages. Such evaluations all require knowledge about what processes and techniques firms use for estimation and investment purposes.

Over the past decade many initial designs of innovative energy capital projects have grossly underestimated costs and performance.* The once-held assumption that such estimates would fall within a certain probability range no longer hold true. DOE's inability to judge the reliability of those past estimates has affected its predictions and plans for future development.

As part of an effort to deal effectively with poor information and to prevent further inaccuracies, Rand has investigated the reasons for

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*See E. Merrow, K. E. Phillips, C. Myers, Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants, The Rand Corporation, R-2569-DOE, forthcoming.

the cost growth and poor performance associated with innovative plant projects. Using the chemical processing industry as a proxy for the infant coal conversion industry, Rand studied the reasons the chemical industry produced poor initial estimates for innovative process plant projects. With statistical analysis we found that cost growth and poor performance are associated with three factors:

1. Poor definition of site characteristics, including lack of consideration of regulatory and environmental problems.
2. Inability to properly assess the extent of technological innovation or associated risk despite prior experience or forewarnings of problems.
3. Poor management techniques, including improper use of dispersed authority, lack of independent reviews or checks on estimates, and failure to seek a diverse project team makeup.

We also found strong indications that many processing firms have recently initiated changes in project planning and estimation in reaction to past mistakes and project failures. In addition, the firms' estimation techniques and processes appear to vary, implying that some firms may be better estimators than others.

These findings raised several questions whose answers would be important to DOE. For one, in their estimating process, why haven't firms taken into consideration such factors as siting or interdisciplinary inputs, project teams, and independent checks? More specifically, what process and techniques do firms use to plan projects and estimate cost and performance? What have firms learned from their mistakes? Have they adapted to this knowledge? How? If not, why not? Do they believe these changes and adaptations result in better estimates? How, otherwise, can estimates be improved?

The answers to these questions may provide DOE with information and criteria to make better judgments about estimates and predictions. For example, when certain risk assessment or cost estimation techniques are used, more reliable estimates may result. But without criteria to assess the reliability and accuracy of estimates, lower estimates may be assumed best; in reality lower estimates may result from poor analysis, lack of consideration of all possible contingencies, or bias.

In response to DOE's need for more information, Rand undertook this exploratory study to determine if differences exist in the approaches firms use to estimate cost and performance, to determine whether firms have made changes, and the nature of those changes.

FOCUS

The major difficulty in estimation occurs early in the formation of a project when information is scarce and uncertainties high because little detailed engineering has been carried out (see Fig. 1). Unfortunately, this is the precise point when an investment decision to continue development must be made. In addition, DOE must make subsidy decisions and supply projections based on these initial estimates. It is a time of high uncertainty and little information, neither of which can be remedied without the commitment of more funds. Then after funds are committed, further engineering and site work will eventually reduce possible errors in estimation. The large differences between the initial estimates and later ones based on more concrete information cause planning, financing, and control problems for industry and the DOE. That is why our study focuses on the estimation processes and techniques used in the project formation stage, on how firms deal with uncertainty and risk inherent at this stage in estimating project costs and why firms choose the methods they use.

Idea Consultation Proposal Decision	PROJECT FORMATION	Study Focuses Here
Project Definition Detailed Engineering Construction Start-up	PROJECT EXECUTION	
Operations	PRODUCTION	

Fig. 1--Stages of a corporate project

We start from the assumption that increasingly poor estimation is caused by the increased uncertainties or institutional changes inside and outside the firm that are not taken into account in the estimation process. In other words, we assume, with some support, that firms in this industry have not been systematically biasing estimates. We also assume that firms are as interested as the DOE in accurate prediction and will have undertaken diligent effort to improve accuracy by adopting new approaches.

LIMITATIONS AND SCOPE

In our initial reconnaissance survey of firms reported here, we looked for trends or indications of how firms might be changing in an effort to solve their past problems. We wanted to indicate the scope and direction of the changes, not to describe them quantitatively. We do not explore the reasons behind specific project estimation errors from the past; we do not examine the criteria DOE may be using to judge project estimates now.

We restricted our interviews to innovative plants or large scale-ups. Our results apply to the most innovative or first-of-a-kind plants. We do not refer to specific firms.

In this initial effort we did not evaluate the success of a firm's approach to project formation but asked what the firm's representatives believed were successful techniques and why other techniques had not been successful in the past. This approach was taken because changes had been recent enough not to have undergone tests of success. We have, however, noted the opinions of the firm's representatives as to why a change had been undertaken, as well as why certain changes were not made. Thus, this study is a short foray into the corporate processes of project formation and estimation under uncertainty. We looked for insights that DOE could apply to better judge the validity and reliability of its estimates. We wanted to discover whether or not firms are aware of what elements lead to poor estimates and whether these elements are taken into account in the estimation process.

METHODOLOGY AND SAMPLE

We first made a literature search to formulate hypotheses that we could test in interviewing firms. We then visited ten corporations in the chemical and petrochemical industry that had experience in building innovative process plants. We interviewed corporate management (usually the heads of corporate engineering, representatives from R&D, and the relevant operations branch) about how they brought an innovative project along from a rough idea in R&D to a more defined concept. We asked about general corporate operations, decisionmaking techniques, technical risk evaluation and criteria, cost assessments, evaluation aids such as computer models, corporate memory, and the review process.

The ten firms we visited for our sample had assets in 1979 ranging from about $300 million to $30 billion. R&D expenditures ranged from about $15 million to $425 million. Sales ranged from $400 million to $45 billion. We asked each firm to rate themselves as compared to their industry as a whole in terms of innovativeness. A scale of 1 to 7 was used with 7 being the most innovative. The average for our sample was 4.2.

ORGANIZATION OF REPORT

There is a rich literature hypothesizing the way firms behave under conditions of uncertainty, and an equally rich literature suggesting that firms do not behave in this way. Section II summarizes the literature as it relates to our focus. Section III presents the generalized process that all firms we contacted use to move a project from R&D to project definition. Section IV discusses details of that process, especially as it relates to the character of the information needed and its flow throughout the firm. These details include corporate structure, the review process, the handling and analysis of information, estimation techniques, the contents of the proposal, the decisionmaking process in top management, and the management of the overall process. Section V presents our conclusions and the policy implications of how industry brings an innovative project from R&D to project definition, including estimation.

II. LITERATURE REVIEW

"Get your facts first and then you can distort them as you please."

--Mark Twain

This section discusses a review of the literature on research and development, cost estimation, information management, and organizational behavior. Because so little has been written on the subject of investment decisions and project evaluation in innovative process plants, we use the literature on R&D portfolio selection as a substitute. We expect that management experience in research and development projects will yield insights into the general problem of information gathering, analysis, and decisionmaking under uncertainty.

CONCEPTUAL FRAMEWORK

In any innovative project unknowns exist: technical, market, and regulatory. Building a plant under full, certain knowledge available to all firms results in normal profits. Successfully building an innovative plant and successfully introducing a new product or process under uncertain conditions may result in "economic rents" to the firm and a market gain over competitors. Innovation is risky, but potentially produces higher than normal profits. Thus, to gain profits firms often proceed to appropriate funds without full technical and market information on the project and its outcome. Instead, an evaluation of incomplete information is used to estimate and assign probability values to project outcomes. Investments in innovative plants are made using this incomplete information, balanced with experienced judgments to capture the potential higher profits.

This estimation and decision process is chronological. In general, two major phases exist: (1) information gathering and evaluation prior to corporate management decisionmaking and (2) the final decision process after all information is available. The decision process is as important as the information gathering, flow, and evaluation, for that is when final judgments of risks and weighing of information take place. The best estimation techniques will not be valid if management misuses them in the final decision.

Prior to the corporate decision, information gathering takes place in several phases: R&D, running of pilot plants, cost and risk estimation procedures, and additional information gathering after the proposal has been sent to management. By information we mean both objectively produced information such as factual, technical data, and judgmentally produced information such as subjective opinions and consensus. Management information gathering and producing techniques at these stages include the use of teams or single person leadership, the use of peer review or review by other functional divisions of the corporation, the use of computer simulation modeling or use of pilot plants, promoting for insightful critiques or reprisals for poor judgments. Evaluation and analysis techniques include the use of computers, standard evaluation packages, test runs in pilot plants, and expert judgments.

The function of corporate management in uncertain situations is to apply its judgment and past experience to weigh the available information and discount it appropriately to arrive at a final investment decision. Management decisions include: (1) the choice of actors who make the final judgment; (2) the process by which the decision is made, such as by vote, consensus, or leadership veto; (3) the weighing of factors in both an informal and formal sense. This last action includes the discounting of individual variables and the weighing of the whole project as against other investment opportunities. It is an art and is highly dependent on corporate memory, personal relations, and individual bias.

Rational decisions are made by people who are able to evaluate information, apply the information to a set of criteria, and decide on a course of action. While many methods of rational decisionmaking exist, they all assume that the underlying elements (Souder, 1978) of the decision are sound:

- Organizational goals and constraints are clearly defined and agreed upon.
- Data are exchanged openly and in an atmosphere of mutual trust.
- Personnel combine astuteness with awareness of personal feelings in order to make sound decisions.

The literature discusses the frequency with which these assumptions are violated, and recommends methods to improve the accuracy and flow of information, as well as methods to improve the ability of personnel to process, evaluate, and weigh the information in terms of established criteria.

GETTING THE MOST OUT OF INFORMATION

Management's goal regarding information is to minimize errors due to mistakes in procedure and errors of belief (Ostwald, 1974, p. 70). Decisions on large, innovative capital projects are dominated by a further source of error: uncertainty. The initial problem in managing information is ensuring that all available, relevant information is included in the process.

The information available to decisionmakers has been divided into three types (Ostwald, p. 49): historical data, involving recorded cost-controlling accounts in ledgers;* measured data, expressed in terms of time or monetary units, such as heat and mass balance equations, evaluations from drawings, specifications, and experiments; and policy data, involving fixed cost projections such as union wage settlements, taxes, government regulation, and insurance.

Analyzing Past Experience

Authors have noted that a firm engaged in many projects would require the storage, access, and retrieval of large amounts of information. The existence and effective use of a high quality information and records system is a key feature of well-managed research and engineering firms (Sandretto, 1968, p. 110). Firms that budget for staff to access and retrieve information, or that index and encourage routine consultation of company records are more effective users of their

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*Note: We would add other non-recorded corporate experience.

information systems (Allen, 1977, p. 185). The method of idea generation and handling (documentation, storage, retrieval, and transmittal) has been identified as crucial to the R&D process (Dean, 1968), and thus to the process leading up to a decision on investment in any pioneer plant.

The place of the Technical Information Center (TIC) in the firm's organization is critical to information access. Firms with a TIC that reports directly to corporate R&D are more effective information users than firms with an independent TIC (Olson, 1978). This implies a need to locate the TIC where information requirements are greatest.

Encouraging Good Information

As information is acquired, it may be useful to employ an information quality control mechanism to make sure that the information contributes to a better decision. This can be done in at least three ways. A quality assurance checklist (Walton, 1976) can be used to test data. Such a checklist could include variables, which serve as indicators of the strength of the data, such as assumptions identified, explicit uncertainties. Feedback reporting (Walton) is an approach in which the information is used by personnel in another (presumably higher level) department, so that weaknesses are exposed through objective independent review. Multiple format reporting (Sandretto, 1968, p. 129) is a project control mechanism that expresses the import of one data set in a variety of ways. For example, by expressing a cost estimate in terms of budgetary expenditure, schedule, and technical achievement, gaps in data may be identified.

Whatever quality control mechanism is used, a crucial factor in "good" information is the explicit recording of assumptions and gaps in data (Twiss, 1974, p. 92). In so doing, subsequent users of the data will not be frustrated or misled by absence of information in their effort to incorporate previous data into current projects.

AVAILABILITY AND UTILITY OF EVALUATION PROCESSES

With all data collected, the "good" data identified, and assumptions made explicit, the information must be prepared for processing by decisionmakers. The final form that the information will take is dependent on the method of evaluation used by the decisionmakers. It is desirable to tailor the method of evaluation to the firm, project, or personnel involved (Ostwald, 1974, p. 168).

The methods of evaluation available can be classified into three major types (Baker and Pound, 1964): decision or game theory, economic or venture analysis, or operations research. Although these methods differ to some degree in their approach, they all involve assessment of risk and incorporation of uncertainty. The difficulty in using these methods hinges on assessing the probability of unknowns. These evaluation methods provide a rational approach for putting information into a useful form. They do not enhance the quality of the data nor do they reduce the need for judgments. Thus, while methods of project evaluation have been generated* and publicized, they might not be widely used (Gee, 1971). While part of the reason for their lack of use is that they

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*Examples of noneconomic evaluation techniques include PERT, LOB, GERT, and VERT. See Digman and Green (1981) for an evaluation of the uses of these methods.

are complex, untested, costly, or not well known (Baker and Pound, 1964), a further explanation is that they are simply not well suited to decisions regarding innovative technologies due to the difficulty of quantifying unknowns. This view is held contrary to the conventional wisdom that managers lack the competence to use the evaluation techniques (Gee and Tyler, 1976, p. 110).

One might expect larger firms to use quantitative evaluation techniques in project selection. Edwin Mansfield found that this was true in large firms, especially chemical and petroleum firms, although he cautioned that the techniques were not relied on exclusively. Their significance in assessment was reduced by the reliance on "professional hunch, intrafirm politics, and a host of other factors..." (Mansfield, 1971, p. 48).

CRITERIA SELECTION AND APPLICATION: IMPROVING JUDGMENT

If the difficulty in using formal evaluation techniques comes from their dependence on highly subjective information, then it follows that organizations that improve estimators' and managers' judgment will also improve the quality of project evaluations and decisions. For purposes of this discussion, judgment is the selection and application of criteria in discerning and choosing among projects.

Selection of criteria is often thought of as self-evident: profit maximization. Yet its application involves more detailed criteria. "The criteria which need to be considered in project evaluation differ with the circumstances of the individual company and its industry" (Twiss, 1974, p. 121). Twiss compiled a general checklist of criteria for R&D

project evaluation, which is also applicable to general project evaluation. Some firms may apply weights or scaled ratings in their use of such a checklist. Twiss emphasizes that the checklist is not comprehensive, but only serves to give a general idea of what criteria should be important to most firms and what factors affect profit maximization.

The capacity of management to improve individual judgments of risk assessment is quite limited, because of individual talents and future unknowns. One method is to train managers in forecasting (Twiss, p. 92). Forecasting specialists or consultants may be hired to aid in preparing forecasts and avoiding pitfalls; however, a resident manager trained in forecasting may make a better forecaster. Armstrong (1978, p. 15) emphasizes that forecast specialists are often overly concerned with method, to the detriment of forecasting accuracy. Managers trained in forecasting may be able to keep their use of forecasting methods in perspective when evaluating projects.

A second method for making better judgments is to use evaluators (and cost estimators) who have served in several capacities in the firm. For example, senior staff in corporate planning and R&D may have managed an operating division and thus be sensitive to operating as well as R&D problems. Gee and Tyler have shown that firms that follow this practice are better at evaluating and selecting projects than are firms that do not.

Third, assessments may be improved through methods that reduce bias. The most common method used in evaluation of projects and assessment of risk is the conference method; however, in this method personalities may dominate expertise (Souder, 1978). Because many procedural methods for reducing bias in evaluation exist, Ostwald (1974, p. 168) suggests that evaluators use multiple approaches to see if outcomes change. Other methods that remove bias from deliberations are Delphi, scenario writing (Twiss), and Q-sort (Armstrong, p. 104). But even if bias is removed, the advantage of conference methods over individual estimates is still not clear.

Judgmental bias can arise from nonmethodological sources. Evaluators may bias judgments because of excessive emotional commitment to a project, or because of a lack of realization of the importance of their work (Sandretto, 1968, p. 91). People with the responsibility for a project often become enthusiastic "champions," thus generating biased estimates. At the same time, evaluators who are removed from a project tend to be more pessimistic and risk-averse, since they know less about a project and are open to worst-case imaginings (Rubenstein and Schroder, 1977, p. 144).

ORGANIZING FOR BETTER EVALUATION

While information systems, evaluation methods, and improved judgments are important tools for project evaluation, the most important elements of good evaluation are informed decisionmakers and free information flow. Organizational structure and managerial techniques can be adopted that complement rather than hinder decisionmaking.

The form of organization can have a significant impact on the flow of information in a firm. Hierarchical organizations tend to suppress information, with those below restricting information in order to protect themselves, or in a desire to please superiors. Similarly, organizations that stress specialization tend to promote rivalries, in which departments or personnel fear that they will expose their weaknesses by revealing a lack of information (Wilensky, 1967).

Organizational behavior literature hypothesizes two distinct management approaches to organization, neither of which probably exists in a pure form. One management approach has been called mechanistic or formalized. A firm with this type organization would have a hierarchial structure: formalized closed communication channels; precise definition of responsibilities and technical methods; a tendency toward vertical communication and authority. In contrast, the organic or informal approach would have a network structure: emphasis on lateral communications especially between functions; responsibility spread over project members; use of problem-solving teams; open communication; continual redefinition of responsibilities and methods (Burns and Stalker, 1980; Duncan, 1980). The organic approach is most efficient in highly unstable, uncertain environments, especially for complex problem solving. Thus, at least for the project formation and estimation functions, firms might be better off using the informal, organic approach. This does not mean this approach should be used in the production or manufacturing functions of a firm, nor that it should be used in later project execution.

Using interdisciplinary groups for problem solving, as suggested by the organic approach, is supported as being superior to individual problem solving (Maier, 1980). With skilled leadership, groups can increase the amount of information for a decision, be more creative, accept responsibility for a decision, and be more accepting of risks. The role of the leader in a problem solving group of this sort is not to make decisions but to relay information, to facilitate communications, and to integrate inputs. The quality of the group solution is highly dependent on the amount of free information exchange and discussion.

Burton Dean has shown that experienced evaluation teams perform better than teams that seldom evaluate projects (Dean, 1968). Accountability and performance were found to be better within teams headed by one person (who is accountable for the evaluation) than by teams with joint responsibility (Sandretto, 1968, p. 98). Management must consider the tradeoff between the benefits of interdisciplinary experience and the possible loss of technical expertise in personnel who devote time to nontechnical functions. While interdisciplinary teams are necessary and helpful, removing technical personnel from their discipline for too long could result in impaired performance (Allen, 1977).

Evaluators should be sensitive to the needs of functions outside their own; incentives should exist to incorporate those needs into the project definition. For example, R&D people need to be aware of operating, marketing, and financial needs in defining a project. Often R&D projects are rejected when they are judged by other departments. Researchers may pursue projects that, although attractive as a research possibility, would not have been pursued had financial and marketing concerns been considered. Sensitivity to interdisciplinary concerns can concentrate research and development in the most productive areas, resulting in better use of R&D resources and a higher rate of approval of projects (Dean, 1968).

HYPOTHESIS BASED ON LITERATURE

The literature search suggests techniques firms can use to make more accurate cost, schedule, performance, and risk estimates for proposals to management.

First, the firm's proposal process would encourage diverse inputs, use of project teams, use of facilitating leaders, and reviews. Second, firms would make use of the many analytic techniques available for estimation, including computer simulations, Delphi or Monte Carlo assessments, and storage, retrieval, and analysis of past data. Use of these techniques, however, would be tempered by the firm's resources and how much real data--not uncertainties and guesses--are available. The most successful firms, of course, would have adopted some of these techniques, but would still partially rely on other methods such as expert judgments and training of managers. In any event, project data from the past, stored ready for easy access with assumptions explicitly stated, would be used for the evaluation of new projects. Third, firms would have standard criteria for evaluating information and would control the assumptions behind the information. Fourth, firms would use reviews, seminars, and written requirements to assure information exchange. Individual management styles would also be used to encourage input and exchange. Fifth, firms would use experienced project teams and provide managers and team members with training in forecasting and experience throughout the various functions of the firms.

A major caveat exists to these hypotheses. James Quinn (1977, 1978, 1980) argues rather strongly that much of the structured, academically based methods of corporate planning and evaluation are not used due to their inability to deal with personal factors, corporate politics, and the creative spark that leads to innovation. Thus, we may find that corporations do not strictly follow evaluation procedures due to the human nature of the organization itself.

III. THE ESTIMATION AND DECISION PROCESS

From our discussions of innovative plant investments with ten chemical processing firms, we found that a common, general method exists for moving a project from R&D to project definition in all ten firms. In this section we discuss the elements of proposal formation and decision held in common by the ten sample firms. Although a common, underlying approach exists, each firm emphasizes certain components or techniques over others; all firms do not operate precisely the same way. Some specific techniques used will be discussed in Section IV.

CHANGE

In our sample all ten firms had had negative experiences building pioneer or innovative plants in recent years. All felt that some of the mistakes could have been avoided; that is, the causes of cost growth and poor performance were not completely external to the firm and uncontrollable. Each has since taken steps to improve its estimation process. Although trends toward the use of certain techniques are evident, no two firms have adopted the exact same combination of possible options. Many of the changes adopted will lead to better performance in the future, the firms believe; however, this assertion cannot be tested until enough new plants are built under the new system.

ORGANIZATION

The decisionmaking body of the firm is often known as the Executive Committee or the Operating Committee (see Fig. 2). The corporate president is always a member. Usually, but not always, the Chairman of the Board and the Vice Presidents of the operating divisions sit on the Committee. The purpose of the Committee is to give final approval to corporate investment decisions, appropriations, and budgets.

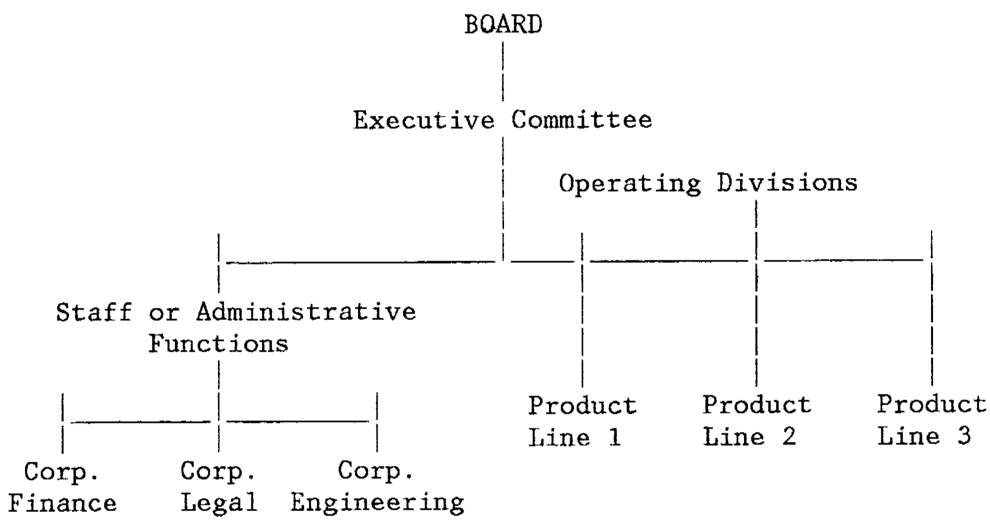

Fig. 2--General structure of firms

All firms are divided into staff or administrative functions and operating divisions. Staff functions can include marketing, sales, personnel, finance, planning, treasury, research and development, and engineering. Not all firms have all these staff functions; however, all have a corporate engineering group. Operating divisions which contain the manufacturing units are the production units of the firm. Each operating unit may have its own staff functions, including R&D and engineering. Duplication of functions is not uncommon. The cost estimation team is always located in engineering within the administrative staff or operating units.

GENERAL METHOD TO PROCEED FROM R&D TO PROJECT DEFINITION

The general path that we found a technical innovation follows from R&D's initial development to approval by top management for project definition is described in Fig. 3. Time in months or years is not stated due to differences among firms and among projects. Nevertheless, the sequence of events shown is constant across the firms surveyed. Differences in corporate structure and the constant evolution of structure found in each firm prevent more detailed description.

1	2	3	4
Idea	R&D: "We may have something here"	Informal consultations; scoping	R&D and operations decide: "this is a feasible project and will need authorization"
5	**6**	**7**	**8**
Cost estimation; interdisciplinary team; inputs and reviews	Coordinator decides proposal is ready for executive committee	Formal signoff by coordinator and involved team	Decision by executive committee

Fig. 3--General proposal process by step

ROLE OF RESEARCH AND DEVELOPMENT

The technical development of an innovation always takes place in R&D; however, the motivation or idea for research may come from another function or from outside the firm. For instance, the marketing unit may perceive a product line and persuade R&D to pursue a technical process for making a product (Step 1).

A technical development team is formed in R&D to develop the initial idea into a real life application (Step 2). The team may be formal or informal. After some work the R&D team perceives that the initial idea is workable and has a useful application. The appropriate operating unit is informed of the work. If R&D is located in the operating unit, the operating unit supervisor may already be informed. Interest and support from the operating unit are solicited. This can be done either formally, through written R&D reports, or informally. In either case informal consultation takes place. After R&D has guaranteed interest and support by the relevant operating unit, work on development proceeds. R&D will seek input from engineering, marketing, and operations. Also, top level management is informed of the potential innovation through formal or informal channels (Step 3). The extent to which inputs from various functions exist at this point varies among firms, but a trend in recent years is for firms to increase inputs at earlier stages. Several firms have recently included environmental and regulatory input at this time.

R&D performs the initial "scoping" or cost estimate on the innovation, often with input from the engineering unit (Step 3). The scoping estimate is used to place priority or ranking on R&D projects and is not accurate enough for capital investment decisions. R&D continues work on development, given positive results of the scoping estimate.

When R&D work nears completion, R&D management decides that the process is technically feasible. R&D and the operating unit decide to proceed to a written proposal to management (Step 4). R&D work may continue throughout the life of the project; however, with the decision to ask for authorization and to prepare a proposal, R&D's singular responsibility for the project ends.

In many cases a pilot plant is built to test the innovative process. The testing of the plant is done by R&D. Consultation and advice for building the plant may be solicited from other functions in the firm, especially engineering. The building or testing may be contracted out depending on the resources of the firm. Companies may also use computer techniques to detail innovative processes, but computer simulations cannot replace actual physical experiments run in pilot or demonstration plants. The computer simulations are used to give indications of possible problems that will later be tested in a pilot plant or to use pilot plant data to show possible design problems.

THE PROJECT TEAM FORMATION AND INFORMATION FLOWS

R&D gives up responsibility of the project to the operating unit or to the forming project team. This project team, as distinguished from the R&D team, can be either formal or informal at this time. The project is now formally supported by the operating unit and is predominantly under their jurisdiction. Formal cost estimation in engineering begins at this time (Step 5).

Diverse approaches exist to the formation of teams. In confirmation of our hypothesis, every firm used project teams. Three separate leadership roles are apparent within these teams.

1. A project coordinator exists whose function is to coordinate the proposal effort. His responsibility is to get the necessary input from all functions and assemble them into a cohesive form for presentation to top management. Coordinators are usually, but not always, in or from the operating unit.
2. Project managers exist whose responsibility is to oversee the actual definition and construction of the project. A single manager will usually head the project team, but is not solely responsible for the proposal creation. Responsibility is usually jointly held by the coordinator and the project manager. Project managers usually, but not always, come from corporate engineering with operating unit approval. As the project moves to the execution phase, the manager becomes solely responsible.
3. Project champions exist whose function is to push the project through to completion. Their enthusiasm is what drives the project through the necessary process. Project champions are always located in the operating unit, and are usually of fairly high status. Cost estimators are kept distant from champions. Coordinator and champion can be the same person.

While the project team is forming, work continues on cost estimation, engineering, and R&D. Finance, marketing, sales, operations and maintenance, environmental and regulatory inputs are solicited by the project leaders as part of the proposal process on a formal and informal basis. Often representatives of these functions are members of the project management team. Exactly who serves on a team seems to be decided in an ad hoc manner in each firm through some agreement between the project manager and project champion/coordinator. Team membership is highly dependent on the type, size, and innovativeness of the proposed project. In recent years the team has included environmental and regulatory inputs.

Unlike earlier years, firms now solicit environmental concerns early in the proposal formation, and finance or planning is included in a formal review of the proposal. However, the amount and value of input from these functions varies from firm to firm, as does the timing for each function's entry into the proposal process. The project coordinator assimilates these inputs into a cohesive form. He decides when the proposal is ready (Step 6) and he makes sure all inputs, formal sign-offs, and work are completed (Step 7).

All ten firms, regardless of size, rely heavily on informal information flow between peers and between the separate disciplinary groups. Many managers interviewed noted that this reliance came in response to incomplete past proposals that led to major cost overruns. Review of one unit's work by other functional units on an informal basis was common, often done on an voluntary basis. By informal we mean that no required reports or schedules were necessary to encourage this communication and information exchange. Although many of the firms did require distribution of progress or monthly reports, this was not the only or even major communication system within the firm. By use of the word informal we do <u>not</u> imply less accurate or less quantitative information. The information is of the same quality as in a formal system, but the delivery mechanism differs, as perhaps does the quantity. Again, we note that although all firms relied heavily on informal communication systems, the degree of reliance on various systems differed among firms.

Disputes over information or conclusions were settled through consensus. In every firm the use of interaction and bargaining to arrive at consensus was a vital part of the process of decisionmaking. The proposal would seldom be passed upward in the organization without consensus of the units below and consensus of other functional units. In the few exceptions to this rule the next higher authority would act as an objective observer and judge, asking difficult questions to ensure that all relevant information was included. Repeatedly we were told by those interviewed that the interaction and consensus process ensured: (1) input by all necessary divisions and functions of the organization; (2) objective work, since review was in part done by those with no special interest in the project; and (3) approval and support by everyone involved.

Each firm used formal sign-off procedures, which act in the same way as informal interaction and ensure that lines of authority are clear. Sign-off indicates responsibility and agreement; however, informal interaction and discussion guarantee that nothing unreviewed or unfamiliar was in a proposal when formal review was requested. Everyone with formal responsibility is familiar with the project, including the Executive Committee.

In general for each firm, as information (the proposal) flows upward in the firm it tends to become more subjective and descriptive as the proposal is changed to ensure understanding and agreement by people with varying backgrounds and interests. At low levels in the firm, detailed quantitative estimation procedures may be used, but by the time a proposal reaches executive management the information has been trimmed down and compressed into a few quantitative expressions and descriptions. Successive judgments are used in the informal consensus process, thus reducing the information to a more subjective form. Interdisciplinary input and review require simplification of information. By the time the proposal is judged ready for top management review, it is usually only a few pages long and contains the consensus judgment of all the lower layers. A proposal is almost never presented without full consensus by all lower levels of the organization. The amount of subjective information and the expertise of personnel, of course, varies from firm to firm and from project to project.

EXECUTIVE COMMITTEE

When the proposal is complete, it is presented to the executive committee. (Who presents the proposal varies as does who is present.) After consideration the executive committee either accepts the proposal and authorizes funds, rejects the proposal, or sends it back for further clarification or reexamination (Step 8). If accepted, funds are authorized for the next step in the development process: project definition. If clarification is needed, the proposal is sent back to lower levels for more work and more specific information.

Through informal communication and formal reporting procedures, the top executives know about every project before the formal proposal is presented. All firms use a committee or group to make the final decision. The makeup of this committee, however, varies widely, as does the background of the members.

From our interviews, informal procedure was stressed in executive review. Most committees use consensus and informal discussion to arrive at decisions. Seldom is a vote taken or strict order observed. Judgment criteria are often developed in an ad hoc manner and change with each project.

Each firm uses triggers for monetary appropriations; that is, each management level has discretionary funds available up to a fixed amount but needs approval from a higher authority for larger amounts. The firms thought this procedure encourages innovation and controls monetary flows. Every firm strictly controls project cost overflows by requiring top management approval for any project overruns and/or incremental appropriations for development and construction. Management often authorizes limited funds for project definition and engineering and later, based on results of this further work, authorizes additional funds. Projects can be dropped easily up to and including project definition. Thereafter, commitments make it more difficult to back out of projects, although there are cases among our ten firms in which completed plants have been abandoned and written off.

COMMON ELEMENTS

In their efforts to reduce risk through increased information gathering, flow, and evaluation, all firms in our sample have several in development: R&D, pilot plant, consensus, proposal, first things in common.

First, they all recognize the futility of searching for perfect information on which to base decisions. Outside competitive pressures are too great and uncertainties are too large on innovative projects. As a result, firms proceed to the executive decision without complete testing of innovative components and without full information. This has led to several past disasters; however, the firms in our sample are now undergoing processes of change to strengthen their estimation procedures so that more accurate estimates will be obtained for future undertakings.

Second, in response to uncertainty most firms use incremental steps appropriation for project definition, and subsequent appropriations. At each level new information is incorporated, but the process does not stall at any level to gather all the possible information. Decisions to proceed to the next level are based on the "best" information given time and cost contraints. At each level the field of possible investment projects narrows as the less certain or less profitable projects are dropped. Appropriations and overruns are strictly controlled by all firms without relation to the size or assets of the firm.

Third, all firms use informal interaction, review, and consensus to ensure diverse inputs by relevant disciplines and backing by all functional units. Each firm indicated that in recent years they have included such disciplines as environmental and regulatory concerns. Also, through this process expert judgments, group consensus, and compromise are used to balance any lack of solid information. Thus, we have found some support for our hypothesis that firms would adopt an organic* mode, incorporating quality control mechanisms as indicated in the literature. However, we did not find that firms use formal bias reducing techniques such as a Delphi series or Q sort. Neither did firms use consistent or constant criteria for judgment. This is contrary to what the literature suggests. Other techniques used are described in the next section.

Fourth, while firms attempted to use analytic tools such as economic, financial, or network planning systems, information was frequently not available for inputs or the related costs prevented its use. Subjective judgments and expert opinions are recognized and accepted methods for dealing with uncertain information.

Fifth, interdisciplinary teams and review are believed to ensure that all aspects of the project have been investigated and all relevant information included in the proposal. Again, this was indicated by the literature.

Sixth, despite these general tendencies, each firm remains unique with varying use of analytic and management techniques. The process described is evolutionary. Many details have been changing over time to adapt to the changing environment in which firms function.

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*See Section II on the literature search. Organic implies lateral, open communications, use of problem solving teams, and a flexible approach.

IV. SPECIFIC TECHNIQUES USED TO DEAL WITH UNCERTAINTY

This section describes in more detail the proposal process, with emphasis on the techniques used to obtain, process, and evaluate that information. Analytic techniques, techniques to reduce bias, and management techniques for assuring sound information are explored.

USE OF ANALYTIC TECHNIQUES

Firms used a variety of analytic techniques to estimate the cost, performance, and technical risk of innovative projects. These techniques included analysis of historical data, use of checklists, models developed by each firm, cost estimation criteria, technical risk models, and computer simulations.

Analysis of Historical Data

We hypothesized that firms would store, retrieve, and analyze past data on projects for use in computing future project costs. Several possible uses of past data come to mind.

1. Firms might review cost components of past plants to determine the percent cost of each particular component. For example, on the average, concrete costs may run 10 percent of total costs, piping 20 percent, etc. This information could then be "factored" into a capital cost for the new plant. This system

could also be used for schedule and performance.

2. Past data might be used to compile lists of major input item costs keyed to inflation. This list could be used with flow charts and preliminary project formulation or definition to arrive at an overall cost of the plant.

3. In a more sophisticated vein, past data might be analyzed statistically to reveal any systematic patterns in past cost overruns or project problems. In this way firms could detect flaws in their methods or gaps in their knowledge that result in later project problems. For instance, Rand analysis* shows that plants incorporating new solids handling equipment will on average have lower performance regardless of whether the firms have prior experience with solids equipment. Firms reviewing their data could discover general principles such as this and adjust their project planning or estimates to include such knowledge.

4. Firms might attempt the same statistically based procedure for technical risk assessments, using data from previously built plants to determine the general performance rating and probability of failure for components of plants. Risk assessments for innovative units could be extrapolated from records of similar units.

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*See E. Merrow, K. E. Phillips, C. Myers, Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants, The Rand Corporation, R-2569-DOE, forthcoming.

Thus in our sample we expected to find that firms had systematically stored data on past projects and actively analyzed that data for factoring, listing, and statistical purposes. In our sample, eight out of ten firms had a central file system for past project data, but only six actually staffed the files; of these only four did so with more than one person. Six of the firms did analyze past data, but all to a limited extent. Most used past data to do cost factoring or to compile check lists. Of the firms that analyzed data only two had a staff whose sole function was to review and analyze data. None of the firms studied did either of the more sophisticated analysis suggested--risk probability or probing for systematic deficiencies using parametric techniques.

Firms gave a variety of reasons why they did not pursue analysis of data more conscientiously, especially for innovative plants. One response was that previous plant experience did not apply to truly innovative plants. Most innovative firms stated they have no reason to review data on other plants, as the information gained would not be useful. Second, circumstances have changed so rapidly in the last few years, especially in terms of environmental, regulatory, and economic conditions, that historical data would not be applicable. Third, many responded that such a system would be helpful; however, they believed it would not save enough money to justify the considerable expense.

Generally, firms did use data from previous plants to a limited extent to determine traditional costs. When dealing with innovative plants, however, expert judgments were used to complement these data. Firms seem to rely on the individual memory of key people to flag potential cost or risk problems of innovative plants.

Who are these experts or key people? In each firm, corporate engineering acted as a pool of experts for the review of proposals. In some firms, corporate planning had the same role. In every firm, there were individuals with wide experience with plants, perhaps previous project managers or long-term managers of operating plants. Key people in the functional administrative units have had experience covering a broad range of topics over their years of service. Their memories of past projects or past operational difficulties form a reservoir of knowledge and expertise to be tapped when needed.

Risk and Cost Assessments

In terms of cost estimation, six firms systematically used past data, checklists, or factoring to produce relatively highly specified costs. Four firms were comparatively much less methodical, not using such methods or relying on general publications for such information. All firms presented cost estimates in a range, usually a plus or minus figure. Three firms assigned the range by expert guess. Five of the firms used a more systematic approach to assigning the range, such as assuming a set of worst possible conditions to reestimate the costs of several factors or components. Two firms varied the approach depending on the importance of the project. Only two firms assigned a probability to their cost estimates. In no case were formal techniques for reducing the effects of an individual's conceptual bias used.

We asked firms what information on the technical risk of the project was included in the proposal to management. None of the firms assessed the probability of the technical risk of the project. In fact only two firms included in the proposal a moderate amount of work on specifying what technical risks were involved. Eight firms assigned a value to the technical risk, but only one arrived at this through analysis. The other seven used expert judgment to assign a value of "low," "medium," or "high" to the risk of the project. Two did not include technical risk in the proposal to management. This does not mean that work to reduce risk was not done or that risk was not considered; it means that firms did not generally try to quantify risk. Expert judgments were relied on to assess risk, and management was satisfied with a low level of detail on estimates of technical risk.

Firms gave a variety of reasons about why this was so. First, most firms noted that techniques such as Delphi were not useful because data were not available for input. Because the plants are innovative there is no way to quantify risk. Second, lists of factors are somewhat useful, but serve only to ensure thoroughness. They serve to get the experts thinking about the problem and to help them focus on what is important. Subjective judgments must still be made. Many people interviewed from engineering thought lists were helpful, but that expert experience was still the key factor. Unfortunately, lists are made from past project data and do not address the problem of possible "surprises" associated with innovations. Finally, several people noted that the executive committee was not interested in detailed risk assessment. The committee assumed that their people knew what they were about and would not present unrealistic projects for review. In one case where the executive committee was made up of engineers, it was assumed that they could judge risk for themselves.

At least for our sample it appears that sophisticated techniques recommended by the literature are not currently in widespread use for cost or risk estimation. Rather, simple straightforward methods are used with heavy reliance on experience as found in individual members of the firm. Yet, of the firms that did use statistical analysis techniques, most had adopted them recently. This may indicate a trend toward the use of more analytical techniques in cost estimation.

Computer Simulations

We originally thought that computer simulations might be used in lieu of pilot plants for some of the process work, presuming that computer programs exist that can successfully predict process flow and reactions in new units. Eight of the ten firms used computer simulations; two did not. However, all the eight firms that used simulations noted that they could not use simulations to substitute for pilot plant work on innovative systems. Computer programs need accurate inputs; inputs are not available if the unit has never been built. When building innovative plants, computer simulations were used only to help determine what tests might be most important to run in the pilot plant and to analyze the results of some runs. Simulations could be used to determine process flows in standard components after testing in innovative components.

Computer simulations are most helpful when pilot plants or component test facilities are used to calibrate the computer program parameters and the program used to predict the outcomes of certain pilot plant runs. If the prediction is inaccurate, the reason is ascertained and the program modified to reflect the newly gained knowledge. If the prediction is accurate, the program is used to predict increasingly more difficult pilot plant runs. This interaction is continued until the limit of information that the plant can produce is reached. At this point the computer program is used to identify problems (such as impurity build-up) that cannot be reproduced in the pilot plant or component test facility.

MANAGEMENT TECHNIQUES

If the ten firms are any indication, firms rely on expert experience and judgments rather than on sophisticated analytic techniques for innovative projects. This is not surprising given the numerous unknowns that are evident in new projects. But what other techniques--as indicated in the literature--do firms use to assure accuracy?

The techniques we found can best be described as reliance on a process of free information flow and review rather than analytic techniques. That process includes (1) organizing to encourage free, early, diverse input; (2) informal relations between functions as opposed to formal or highly structured relations; (3) use of independent checks by corporate engineering, finance, or corporate planning; (4) the attitude of the executive committee; and (5) training of project managers.

Early, Diverse Inputs

All firms in our sample promote early inputs into the estimation process. For many firms the proposal formulation is the beginning of the formation of the project execution team, and the people included in the early inputs will become members of the team. Note from Table 1 that both engineering and environmental or regulatory concerns are included almost from the start of the project, a development over the last ten years. Also, early corporate engineering input is a recent change for most firms.

Table 1

NUMBER OF FIRMS (OUT OF 10) REQUIRING INPUTS AT VARIOUS STAGES

	Stage[a]				
Functions	R&D and Scoping	Consul-tation	Proposal	Decision	Project Definition
Corporate Engineering	7	3	--	--	--
Cost Estimation in Corporate Engineering	1	6	3	--	--
Operations and Maintenance	1	5	1	--	3
Environmental and Regulatory	3	7	--	--	--

[a] The stages refer to those in Fig. 3.

Firms use various management techniques to encourage these inputs. First and foremost, in our sample, project management has been adopting organizational forms that encourage free discussion, input, and flow of information. The trend has been away from the mechanistic approach and toward the organic approach--only in the project formation process in the firms sampled, not in the firm's general structure. However, the project formation process touches virtually all functions.

Every firm responded that they had been through or were going through a reorganization effort which emphasized inputs from all functions in the organization. Several have recently adopted matrix-like organizations to encourage this. Wherever the proposal inputs are coordinated, there are people to act as facilitators of the process. Three firms have people designated as facilitators within each operating unit. Their purpose is to know who in the firm has the expertise needed to pull together the inputs and to assure consensus among functions. Other firms have staff people who act in this capacity. In one firm this coordination effort was part of the planning office. Generally, it is the larger firms that employ facilitators. In smaller firms, people have often worked with each other before and know each other's capabilities, obviating the need for a facilitator.

In all cases, this informal consultation was accompanied by a formal sign-off and review procedure. Firms commented that the list of functions involved in this activity has expanded in the reorganization efforts. However, key review functions are finance, marketing, planning, and corporate engineering. In all cases, these functions were consulted prior to any formal sign-off.

Why have firms attempted to receive early and diverse inputs? All firms responded in the following way:

- Diverse inputs guard against project champions having unobstructed sway in the decision. Several firms noted bad experiences when plants were built on the recommendation of one person. These firms noted that the plants would not have been built had more people been consulted.
- Diverse inputs ensure more complete information for a decision. Several firms noted plant failures because some function, such as environmental or operations and maintenance, had not been consulted in the proposal process.
- Early inputs save the firm from making costly mistakes later.

Informality Trend and Group Consensus

Diverse and early inputs are valuable, especially if possible problems are noted early. Yet, management may inadvertently discourage people from offering "bad news" concerning a proposed plant. This could be disastrous because designers must know about possible future problems to avoid costly errors. Thus, early inputs must encourage the benefits as well as the possible problems and additional costs. Firms are tending toward more open, informal communications in conjunction with early inputs to encourage the flow of all information.

Specific techniques being used are difficult to define because they depend largely on the individual styles of managers, on their being available, being open to criticism, and promoting constructive criticism. Most firms required that the project be backed by functions at the low as well as the high (executive) levels, which forces people backing the project to consult actively with other functions. For example, if the marketing people have some problem with the product quality, they will not agree to formal sign-off until it is resolved. Thus, formal sign-off forces the operating and engineering people to talk with marketing to resolve the problem before proceeding to the executive committee decision.

Further, through the matrix-like organization and the use of informal proposal and project teams, responsibility is spread throughout the firm by functions. The team or group becomes responsible, not just the single leader,* and they must balance enthusiasm for the project with cautious regard for the company's best interest. We asked about the motivations for offering support as well as criticism. Firms responded that if a project failed, then blame would fall on the project manager and the supporting operating unit champion. These two people carry formal responsibility. However, many firms indicated that the executive committee is well aware of who may have done poor work or which function was particularly at fault. An appropriate amount of disfavor, sometimes in the form of dismissal, will be felt by people other than the formal managers.

Thus, open communication channels and cooperation, as well as constructive criticism, are to everyone's benefit. By being open and available managers encourage bad as well as good news or information. Assigning group responsibility and requiring consensus encourages all

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*Note that shared team responsibility is considered beneficial only during the project formation phase. During project execution, it is important to have single-person authority.

inputs. Stiff penalties existed in all firms for those who would not cooperate.

More specifically, we found that firms we rated as informally* structured for information flow tended to be (1) those with the earliest inputs; (2) those that responded well to negative criticism; and (3) those that rated themselves among the more innovative firms.

Independent Checks and Corporate Engineering

Another management technique used was to require independent checks of the proposal estimates; this was often the job of corporate engineering.

In firms where estimates are initially prepared by staff in the operating unit, the estimates are later checked by Corporate Engineering to assure their accuracy. This is part of the input and consultation process as well as formal sign-off. In these cases corporate engineering has a separate reporting relationship to the executive committee. In other firms, corporate engineering is responsible for all the estimates, which are reviewed by the operating unit staff and the finance and planning functions. In one corporation, a separate group set up to review all proposals reports only to the executive committee. In all cases some sort of independent check and approval of estimates is required. Isolating this function from the rest of the firm and assigning the role of devil's advocate to group decisionmakers encourage objectivity.

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*Our subjective informality rating included consideration of a matrix or organic structure, formal versus informal communication channels, the attitude of management toward scheduling, goals, and flexibility, and the use of reviews and inputs that were not required.

Firms also use outside contractors to check estimates. One firm required this check on all proposals; five required it depending on the project; and four never required it on early estimates.

All firms have adopted these methods of independent checking to avoid excessive championing of a project and lack of objective review. Each firm noted poor project results when estimates had not received an independent review. Each firm strongly recommended the review by an independent function within the firm.

Training of Management

To encourage managers to take a broad view and to recognize all possible contingencies in project formulation several firms have initiated training programs. Two firms in particular required project managers to have served in several functions in the firm; job hopping within the firm was encouraged. Three other firms used this technique, but with less commitment. The remaining five had not adopted this policy. However, the two firms that enthusiastically supported experience schooling of managers did not have formal courses to offer them. Four of the firms that did not encourage job movement had developed their own courses or sent their project managers to outside courses.

SUMMARY

Table 2 summarizes our findings on each firm. The variety of approaches becomes evident when viewed in this form; yet common experiences and beliefs are evident. These are summarized in Section V.

Table 2

SUMMARY OF TECHNIQUES USED BY SAMPLE FIRMS

Category	Firm									
	A	B	C	D	E	F	G	H	I	J
Innovativeness of firm[a]	4	2	6	1	6	4	6	3	6	4
Who prepares cost estimate[b]	Eng	Out	Eng	Eng	Eng	OpsEng	Eng	Eng	Eng	OpsEng
Independent, in-house check on cost estimate[c]	Y	S	Y	N	S	Y	N	Y	Y	Y
Outside check on cost estimate	S	N	S	S	Y	N	N	S	N	S
When project team formed[d]	1	3	2	5[e]	2	3	2	2	5	3
Who is on project team[f]	Eng, Ops, O&M, ad hoc, not Fin	Eng. Ops, Fin	Eng, Ops, O&M, Inst	Eng, Ops, Man, R&D, Mrkt	Eng, O&M, R&D, Fin, Mrkt, Man, Env	Eng, O&M, R&D	Eng, Spec	Eng, Ops, R&D	Eng, Ops, Fin	Eng, Mrkt, Ops, Inst
Corporate informality	Med	Med	Hi	Med	Hi	Hi	Hi	Med	Hi	Med
Analyze past data and historical experience?	Y	N	Y	Y	N	Y	N	Y	N	Y
Ability to assess technical uncertainty	Med	Lo	Med	Lo	Lo	Lo	Lo	Lo	Lo	Lo

[a]We asked each firm to rate itself on its level of technical innovativeness with respect to other firms that build process plants. The scale was from 1 to 7, "one" indicating that the firm was a follower, and "seven" indicating that the firm was a leader.

[b]Eng--corporate engineering
Out--the estimate is prepared by another firm
OpsEng--engineering groups within the operating divisions.

[c]Y--yes
N--no
S--sometimes

[d]Numbers refer to Fig. 3; in general, low numbers refer to early formation of the project manager's team.

[e]A true project team (one that remains constant for the whole project) does not actually form until after funds have been appropriated by the EC (Executive Committee). However, a temporary team is appointed during the first cost estimate.

[f]Eng--engineering
Fin--finance
Ops--operating division
O&M--operating and maintenance
Inst--instrumentation
Man--the plant manager
R&D--research and development
Mrkt--marketing
Env--environmental
Spec--specialist

V. CONCLUSIONS AND POLICY IMPLICATIONS

CONCLUSIONS

We found some techniques and ideas that surprised us and others that did not. In answer to the general area of inquiry, "Are firms changing?" we found that each of the ten firms we interviewed has recently initiated a process of change in response to increased uncertainties and past project failures. This change has come after several years (mid-1960s to mid-1970s) of relative stability. As the literature suggests, firms are tending toward increasingly open communication, increased lateral communications, and earlier encouragement of diverse inputs. Some firms have adopted more sophisticated techniques or have more strongly encouraged open communication than others. Some firms have had more experience under new proposal formation systems than others. The implication is that some firms may be better than others at putting together a complete project proposal package. Our research indicates that the firms believe this is so. Based on experience, the managers interviewed believed that firms using sophisticated analytic techniques and open communication with diverse inputs are better cost and risk estimators. Table 3 summarizes our findings about what methods or techniques our sample of firms and the literature associate with increased estimate accuracy and completeness. Inclusion in the list does not imply that these techniques are necessarily used, only that on the basis of their experience firms believe their use will contribute to more accurate estimation capability.

Table 3

TECHNIQUES BELIEVED BY SAMPLE FIRMS TO ENCOURAGE ACCURACY

Techniques
Structure
1. Organic Organization
2. Matrix Organization
3. Early Formation of Project Team
4. Use of Interdisciplinary Team
5. Estimators Separate from the Operation Unit
Evaluation
6. Central Storage of Data and Access to Those Data by a Staff
7. Historical Data Used for Listing and Factoring
8. Historical Data Used for Statistical Analysis of Costs and Technical Risk
9. Computer Simulations
Input and Review
10. Early, Diverse Inputs
11. Informal Communication Channels
12. Independent Inhouse Review or Outside Contractor Review
13. Use of Concensus and Group Responsibility
14. Use of Facilitators (in large firms)
Other
15. Incremental Funding
16. Training of Managers
17. Job Switching by Managers
18. Close Scrutiny by Executive Committee

Firms had adopted different analytic techniques. In our sample of ten firms, none had adopted sophisticated techniques for analysis of past data; only six analyzed past data. Several did so in a systematic and timely manner; however, none used the more sophisticated statistical analyses possible. Formal techniques for reducing bias in subjective judgments were not adopted. Risk assessments were arrived at subjectively by seven firms. Cost and performance estimates were derived using minimal analytic techniques, relying heavily on subjective judgments. Computer simulations were used to a limited extent, apparently because of cost considerations and the inability to quantify unknowns. In general, the firms we interviewed believed analytic techniques valuble but difficult to use. Thus, analytic techniques suggested by the literature have not been systematically used, although firms believe their use could increase accuracy somewhat. We judge that they may be more widely adopted soon.

Instead of clearly defined analytic techniques, firms have encouraged accuracy and quality through management, relying more on interaction and consensus of diverse functions to obtain complete information for decisionmaking. Open communication, diversity, and early inputs have been encouraged by adopting an "organic structure," requiring consensus, using facilitators, requiring formal sign-offs, and training employees. Independent reviewers both within and outside the company act to assure accuracy; group responsibility for the project outcome ensures that risk is taken into account. The decisionmaking body, usually known as the executive committee, is an integral part of this process since it encourages the open flow of communication and forces team consensus before review. This committee is also responsible for maintaining independent checks throughout the firm. Management techniques used are those the literature suggests are appropriate to uncertain, risky situations and those which increase the value of available information.

Although the firms in our sample all agree on the management and analytic techniques that should be used (a finding in and of itself), each firm is unique in the extent and manner in which it has adopted these techniques. Given the techniques described do lead to more reliable estimates, the clear implication is that some of the firms in our sample are better estimators than others. For instance, compare firms A and B in Table 2 (see Section IV). Firm B has adopted many techniques believed to lead to less reliable estimates (inconsistent use of independent check, no analysis of past data, few interdisciplinary functions on the project team). With further research, the usefulness of the techniques listed in Table 2 as criteria for accuracy could be proved or disproved. Furthermore, the additive effects of these techniques and the marginal usefulness of each might be found. It is reasonable to propose that a firm need not adopt all of these to become a reliable estimator; some methods are probably more important than others.

In conclusion, our sample suggests that firms in the chemical/petrochemical industry are changing in some of the directions indicated as appropriate by the literature and the results of our previous work on pioneer process plants. It is not yet clear, however, that firms are better estimators and that mistakes will not occur in the future. What is clear is that firms vary in their approaches to estimation, that all firms are learning, but that one should expect distinct differences in the accuracy and reliability of estimates between firms.

POLICY IMPLICATIONS

In terms of energy commercialization programs several implications are clear:

1. DOE should be familiar with each firm's level of effort and project evaluation procedures when comparing projects for program funding. The information and effort that go into an initial project estimate prior to project definition varies from firm to firm, as does each firm's ability to factually and quantitatively analyze the prospects of a project. Thus, some firms may give more accurate or less biased estimates than others. "More accurate" in this case may mean higher dollar-wise estimates since more factors such as operation and maintenance and environmental problems would be included in more accurate estimates. Low estimates based on less information and poor evaluation will only result in costly growth later. DOE should review each proposal to ensure that competing proposals are comparable in terms of information, analysis, review, and independent checking. With further research a set of criteria might be developed that could be used by DOE to more accurately judge project proposal accuracy.
2. Each firm has developed a unique information gathering process. To encourage and gather all relevant information takes time, special personnel relations, and is not easily subjected to rigorous rules or regulation. Regulations, such as requiring strict scheduling, may be harmful to this process.

3. Firms may benefit, however, by adopting the use of selective, sophisticated analytic techniques and management techniques since more accurate estimates may result.

If policies could encourage the combined use of quantitative analysis techniques and past data analysis with the preferred informal exchange of information on all levels, then one could expect more accurate and complete estimates. Few firms in our survey have combined both these approaches. It is not clear that the government can effectively mandate such a policy since the policy's effectiveness will vary with the internal workings of the firms. Nevertheless, because of the crucial importance of estimation techniques and management practices to project evaluation, the federal government must be aware of the varying levels of expertise and varying practices within the industry.

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